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Release of suspended sediments during the 2019-2020 drawdown of Morrow Lake (Kalamazoo River, Michigan)

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Stephen K. Hamilton
Kellogg Biological Station
Michigan State University
hamilton@msu.edu

Morrow Lake, a reservoir on the Kalamazoo River above Comstock (MI), was drawn down to its original streambed level in November 2019 to replace the gates, and remained drained until mid-December 2020. Although efforts to mitigate sediment release from above the dam intensified over the summer of 2020, large amounts of new sediment deposition and high concentrations of suspended sediments were visible well downstream throughout the drainage period.

In this report, I summarize measurements of the concentrations and transport of total suspended solids (TSS) in water samples collected above and below Morrow Lake (Figure 1). This sampling is part of a long-term study of water quality in multiple waterbodies in the region and was funded by a grant from the US National Science Foundation. We sampled water over nearly 3 years preceding the drawdown as well as during the drawdown period. The concentrations were interpolated between sampling dates to estimate daily values, which were multiplied by daily discharge measurements to estimate total loads (transport). Methods are described in more detail at the end of this report.

A subsequent report will examine the concentrations and transport of phosphorus.

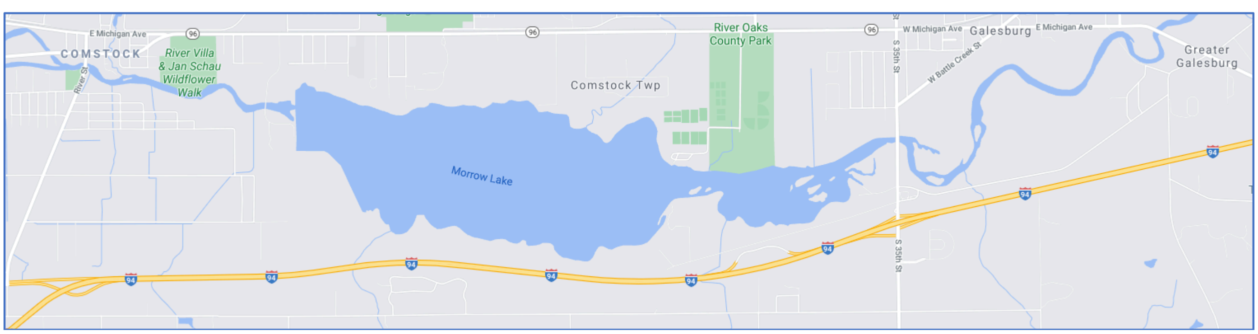


Figure 1. Map showing Morrow Lake (from Google Maps). Inflowing water was sampled at the 35th St. bridge in Galesburg (right bank facing downstream) and outflowing water was sampled just upstream of River Road in Comstock (left bank). The USGS discharge data come from the gauge just downstream of River Rd. No major tributaries enter between the two sampling points.

The dam that forms Morrow Lake is operated as a run-of-river system, meaning that reservoir water levels are kept constant over the year and inflow is balanced by outflow, although short-term variation in water release creates abrupt changes in water level and discharge immediately downstream of the dam. According to the hydropower company, this variation is caused by brief shutdowns when units need regular maintenance, rather than by hydropeaking in response to electricity demand fluctuations. [*This paragraph was revised on 23 Feb 2021*]

Export of suspended sediments

Prior to the drawdown, TSS concentrations in the river inflow and outflow tended to be relatively low, and there was no consistent increase or decrease as river water passed through the reservoir (Fig. 2). Reservoirs characteristically trap suspended sediments in inflowing river water as flow slows down, but growth of algae as well as occasional sediment resuspension can generate new solid material in the water column, and thus the suspended matter flowing out of Morrow Lake was probably not the same as that flowing in. Under normal water levels, most algal growth in Morrow Lake occurs at low discharge during summer (Reid and Hamilton 2017).

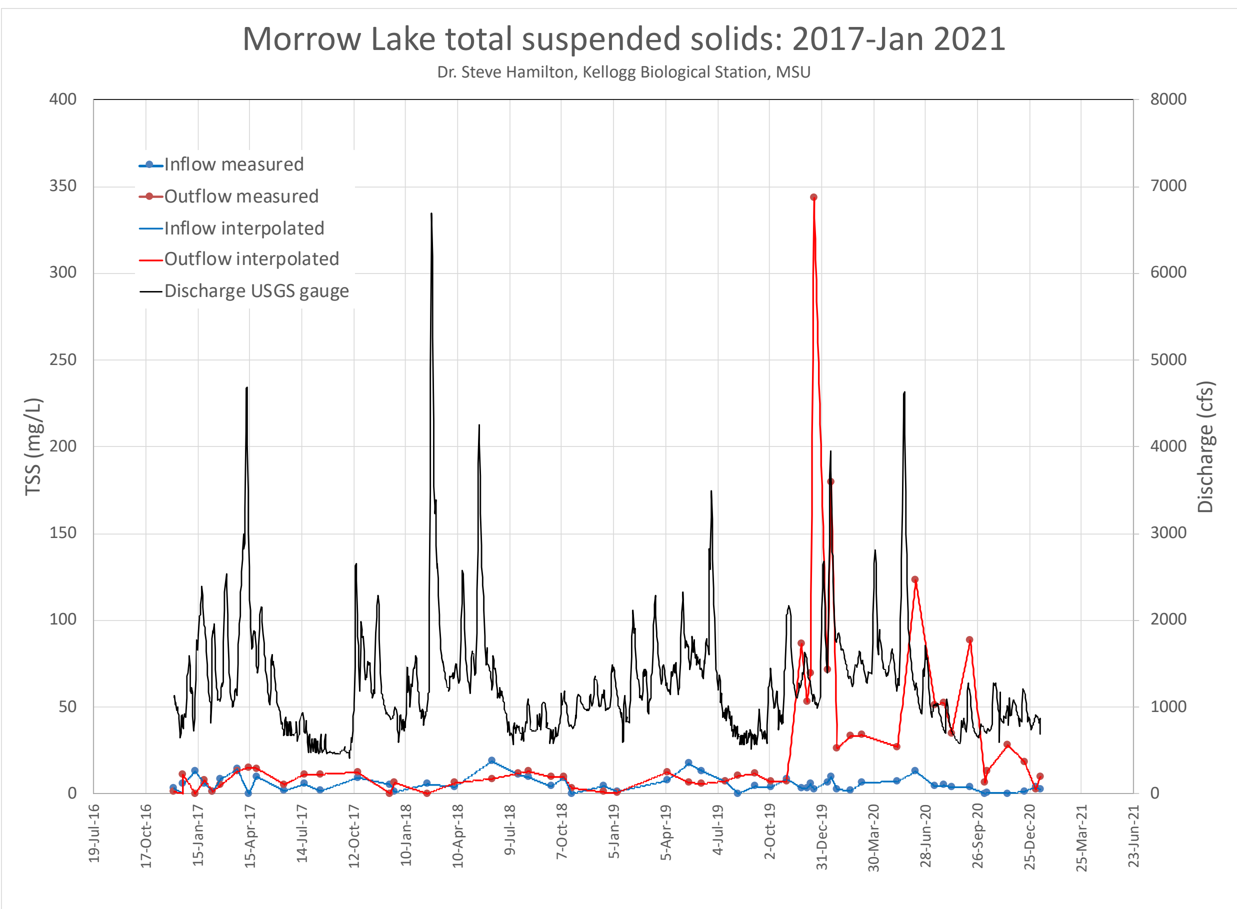


Fig. 2. TSS concentrations and river discharge preceding and during the drawdown period.

The period of reservoir drawdown beginning in Nov 2019 coincided with elevated TSS concentrations in the outflow, but resulted in no visible increase in discharge compared to the preceding years. In this and the other charts presented here, chemical measurements are indicated by symbols, and the lines connecting the symbols indicate how we estimated concentrations on intervals between sampling by linear interpolation.

The drawdown period can be examined more closely in Figure 3, which shows the same data as in Figure 2, but only for the drawdown and refilling (Nov 2019–13 Jan 2021). The frequency of our sampling, which was constrained by COVID-19 restrictions, missed some of the peaks in discharge. In particular, we missed a large discharge peak in late May 2020, which might have mobilized more sediments. However, the highest TSS concentrations we observed (18 Dec 2019) did not coincide with or follow a peak in discharge.

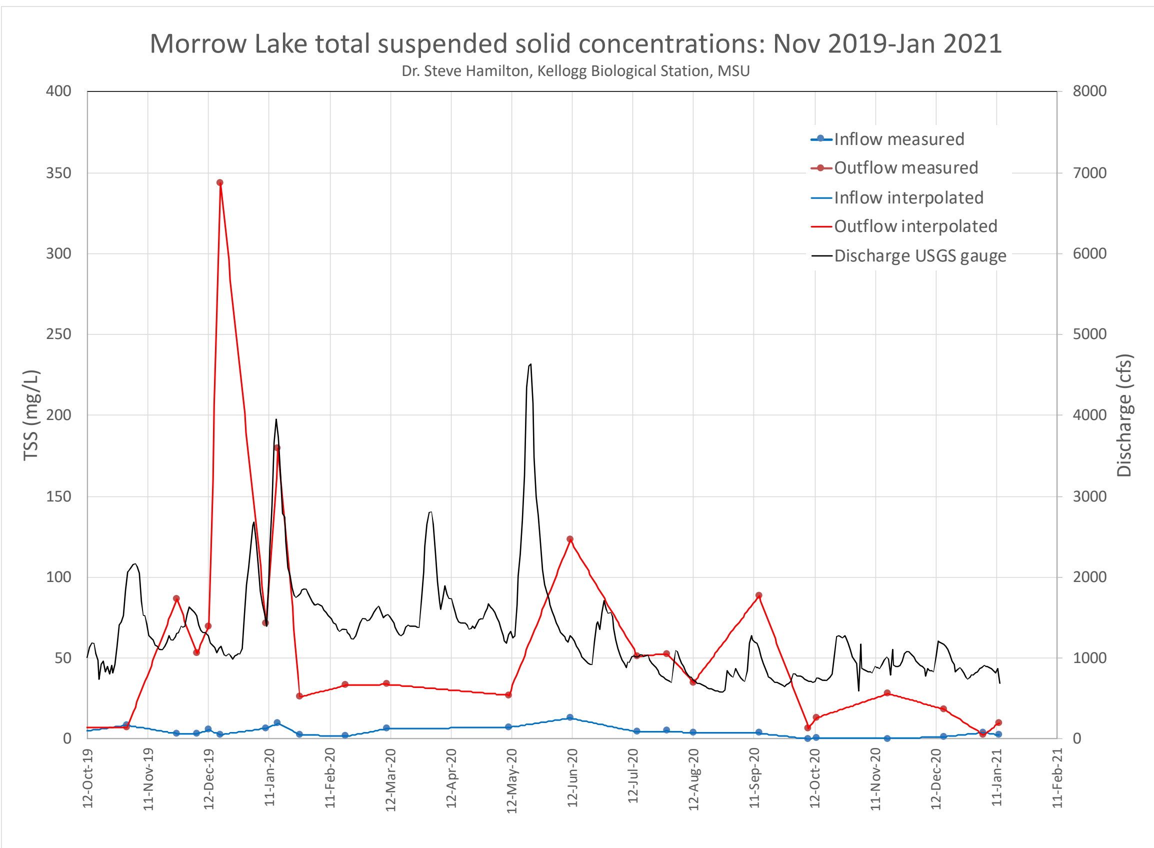


Fig. 3. TSS concentrations and river discharge during the drawdown period.

Daily TSS concentrations estimated by interpolation between sampling dates were combined with daily means of discharge from the USGS gauge to estimate the total load (transport) of suspended sediments that passed by the downstream sampling site during the drawdown period (Fig. 4A). Daily load was calculated as concentration times discharge. Variation in load is partly explained by pulses of inflowing river discharge (Fig. 4A), which temporarily increased reservoir water levels (Fig. 4B). However, as noted above, a high inflow period in May 2020 was not sampled, and a peak in load in Dec 2019 did not coincide with a discharge pulse.

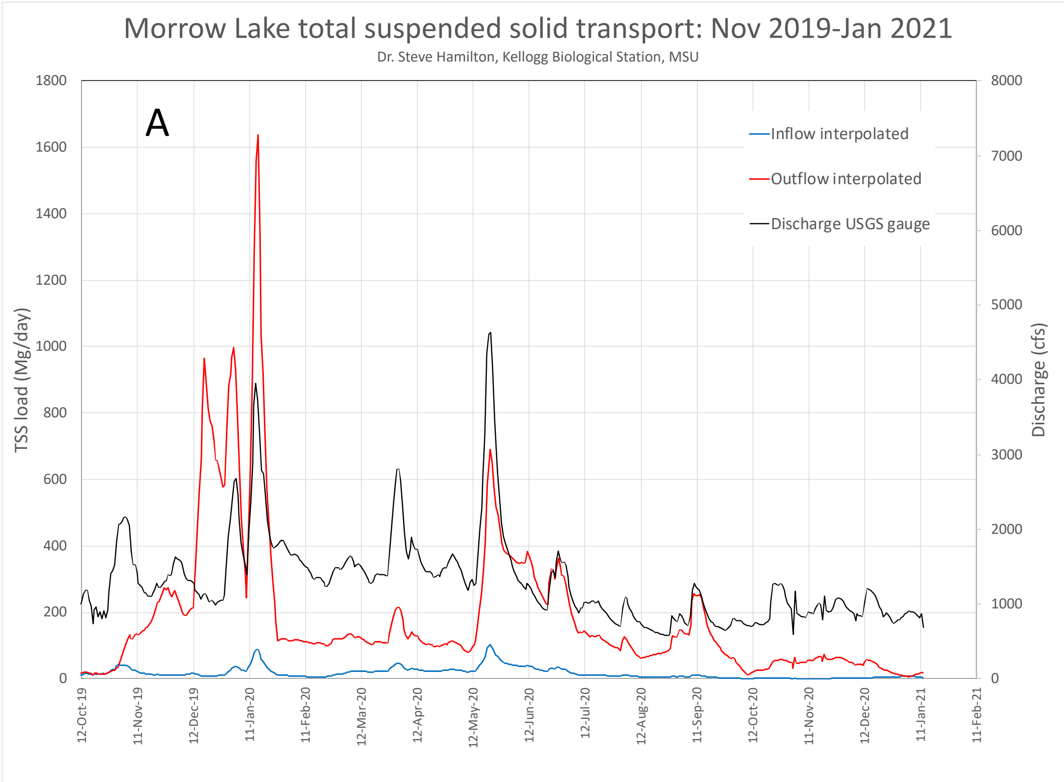
Outflow load minus inflow load, which is the difference between the two lines in Fig. 4, showed the elevated outflow load can be attributed to sources within the reservoir. **The sum of daily loads over the drawdown period, corrected for inflow loads, was 78,390 metric tons** (86,385 short tons, which is the US system) on a dry weight basis.

We can roughly estimate the volume that this release of suspended sediments would occupy once it settled to the bottom of the river. For this we need to know the bulk density of sediment deposits. Assuming that the settled sediments would eventually have a similar bulk density as the fine sediment deposits in the reservoir from which they originated, we can use the average of available measurements made in Morrow Lake in recent years. Two sources of information were available: 1) the Hamilton lab took 5 sediment cores in a longitudinal transect across the reservoir, which had a mean bulk density of 0.23 g/cm^3; and 2) measurements made as part of a study of submerged oil overseen by the US EPA after the Enbridge oil spill included 13 sediment cores from the main body of the reservoir, which had a mean bulk density of 0.296 g/cm^3. I used the weighted mean of these values, which is 0.278 g/cm^3, for present purposes.

The total volume of the TSS load, once settled on the bottom of the river, was thus estimated as its total mass divided by bulk density. After unit conversions, the volume was estimated to be 282,000 m^3 (= 9,956,600 ft^3 = 369,000 cubic yards).

To provide an idea of how much this volume of sediment could affect the river below the dam, consider that the river width downstream of Morrow Lake is about 150 ft (46 m). **The 282,000 m^3 of sediment that was released could cover the entire river bottom with a layer 0.3 m (1 ft) thick for about 20 km (12.5 miles)**, equivalent to a total area of 940,000 m^2. A 20-km reach below the dam extends well beyond the D Avenue bridge in Cooper Township.

A similar calculation can be made to estimate the depth of the sediment layer that would have to be eroded from Morrow Lake to produce the increased TSS load in the outflow. The total area of Morrow Lake at normal water level is about 4,451,000 m^2. Erosion would undoubtedly have occurred in a spatially heterogeneous manner, but if it were evenly distributed across the lake bottom at the same bulk density (0.278 g/cm^3), the 282,000 m^3 of sediment equates to a layer only about 0.06 m (2.4 in) thick. Aerial views of the reservoir during the drawdown show the formation of channels in the center of the lake bottom (Figure 4), and a field visit revealed stumps that had been exposed in the new river channels (Figure 5), so the actual depth of erosion where flowing water persisted was likely considerably greater than 0.06 m. Therefore, the estimates of total sediment release based on TSS measurements appear plausible.



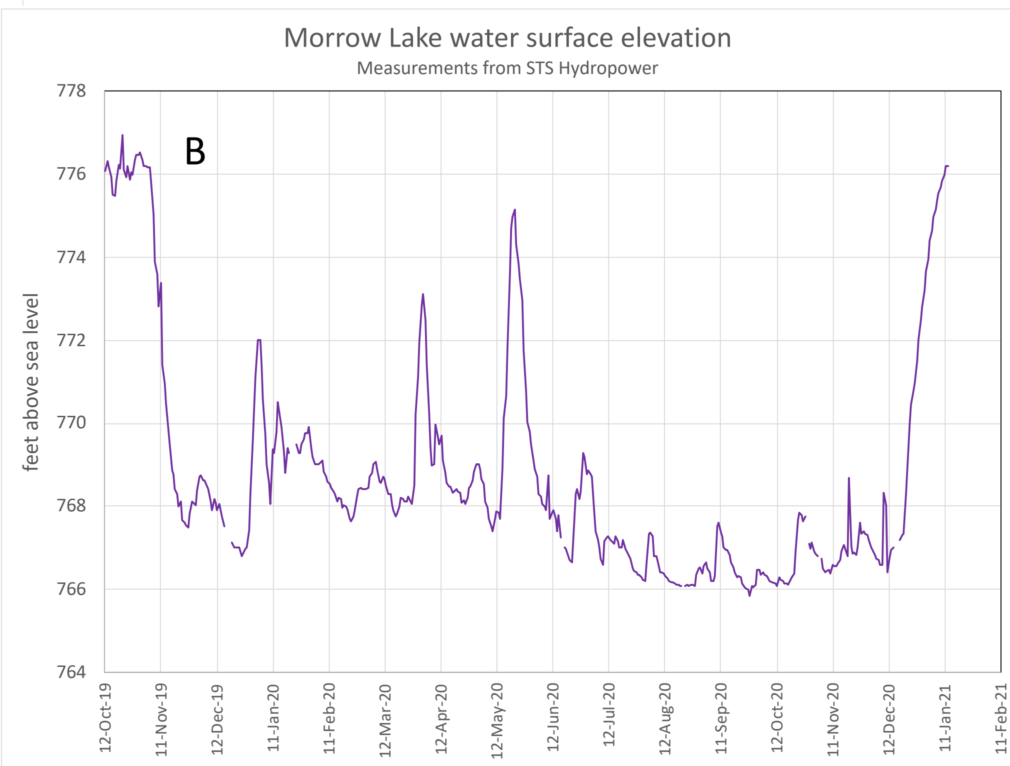


Fig. 4. A) Daily TSS loads and river discharge during the drawdown period. B) Daily reservoir elevations (water levels) measured at the dam headwater during the drawdown period. [Fig. 4B added 24 Feb 2021]

Fig. 4. An aerial view of Morrow Lake looking east from near the dam on 13 July 2020 shows the spatially variable erosion of fine sediments. Photo courtesy of the Kalamazoo River Watershed Council.

Fig. 5. Stumps and eroding organic sediments became visible during the drawdown (Sep 2020).

Details on methods

The Morrow Lake inflow and outflow were always sampled on the same day. A polypropylene "dipper" (a collecting cup on the end of a 2-m pole) was used to collect a river water from 0-50 cm depth. After rinsing the polyethylene sample collection bottle with sample water, one liter was collected for lab processing and analysis. A multisensor sonde that records pH, specific conductance, temperature and dissolved oxygen was placed into flowing water prior to collecting a water sample for lab analysis, and readings were taken after stabilization (at least five minutes). Pictures were occasionally taken if significant changes at the site were noted.

The upstream (inflow) sampling site is about 20 m above the 35th St bridge in Galesburg, along the right bank facing downstream. Samples were collected in flowing water approximately 3 m out from the river bank. The river bed is made up of large boulders at the upstream sampling location.

The downstream (outflow) sampling site is located about 20 m above the River Road bridge in Comstock, along the left bank facing downstream. Samples were collected in flowing water approximately 1.5 m out from the river bank. The bank at this site is lined with rip rap and the water drops off steeply.

To measure total suspended solids, up to 1 L water was filtered through a glass-fiber filter (Pall A/E, 1 micron pore size) until the filtration rate slowed. Prior to use each filter had been dried at 60 C and weighed (tared). Material on the filter was subsequently dried at 60 C and the filter was weighed again, with the increase in weight representing the dry weight of material on the filter. Division of that dry weight by the water volume filtered yielded the concentration in the original sample.

Discharge data for the Kalamazoo River at Comstock (USGS station 04106000) were downloaded on 1 Feb 2020 from https:\\nwis.waterwatch.usgs.gov. Reservoir water level data were provided by STS Hydropower, LLC.